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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

THE COOLING OF TURBINE BLADES

by

Zhou Qin-sheng and Wang Feng

FOREIGN TECHNOLOGY DIVISION

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THE COOLING OF TURBINE BLADES

Zhou Qin-sheng and Wang Feng

Since the birth of the aviation gas turbine engine, everyone has ceaselessly come up with ways of raising the temperature of gases in a turbine before combustion. The reason for this is that, when the precombustion gas temperature in a turbine is raised, the engine is not only able to generate a larger amount of thrust without having to increase the weight of the engine, but also, in any given unit of time, every kilogram of thrust produced will require the consumption of a reduced amount of fuel. For example, if we consider the case of a turbine engine which produces 3500 kilograms of thrust and, if we take the case in which the temperature is raised from 1200° C to 1500° C, then the thrust to weight ratio will be increased 15% and the rate of fuel consumption will be lowered by 8%. This will cause the flight of this aircraft to be more economical.

Many types of metallic materials will turn soft at high temperatures and when they are subjected to the effects of various forces, it is easy for them to undergo deformations. Because of this fact, master workmen wait until the metal is red hot before they take the forging hammer and make it into various shapes. When engines are in operation, high temperature combustion gases impact against turbine blades with very high speed; this causes the combustion gas turbines to revolve with extremely high speeds. How is it possible to guarantee that the turbine blades will operate reliably at high temperature conditions? One method for assuring this is to make experimental productions of new alloy materials which have extremely high strength under high temperature conditions and are capable of withstanding these high temperatures. Another method is to carry out some type of cooling of the turbine blades, thereby lowering their operating temperature.

Translator's Note: Diffusion or diffusion method should read divergent.

As far as methods of cooling turbine blades are concerned, there are a large number of them. However, generally speaking, all these methods of cooling fall into the four types listed below.

Convection cooling. Figure 1 is a diagram of a turbine blade which makes use of convection cooling. From a compressor air is forced to flow through small holes in the base of the turbine blade. The air flows through these small holes in an axial direction in terms of the long axis of the blade and finally flows out of the tip of the blade. During the time when the cool air and the hot metal are in contact with each other, the air can carry away heat from the blade. This causes the temperature of the blade to drop.

How is it possible to cause large scale drops in the temperature of the turbine blades? The first way is to increase the flow speed of the cooling air as it flows through the blade. The faster the speed of the air flow, the better will be the cooling results. In the summertime, when one is using a fan to fan oneself, the larger the amount of air from the fan or the faster that the air comes out, the cooler a person feels. This is the same principle. A second method is to increase the number of cooling holes. If the number of cooling holes is somewhat increased, then the results of the cooling will be more pronounced. Besides this, the geometrical configuration of the cooling holes also has a large influence on the effectiveness of the cooling. Figure 2 is a diagram of various different configurations of the path through which cooling air can pass. In cases where the areas of the cross sections of the cooling holes are equal, oval-shaped and odd-shaped holes have better cooling results than are produced from round holes. This is due to the fact that the circumferences of these two first types of holes are longer than the circumferences of round holes. Because of this fact, it is possible to increase the area of contact between the cooling air and

the blade. Practically speaking, this method is the equivalent of increasing the number of cooling holes. Obviously, the number of cooling holes cannot be too large. If it is too large, then not only will there be difficulties with manufacture, but also such a large number of holes would greatly reduce the strength of the blade.

If one makes a comparison with blades which are not cooled, then one finds that the use of convection cooling makes it possible to lower the average temperature of the blade concerned by approximately 200 degrees.

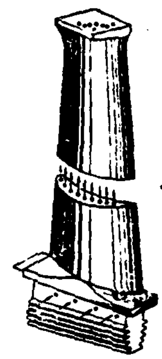

Figure 1. A blade cooled with convection cooling.

Jet-type cooling. When the surface of a turbine blade is at a temperature which is extremely or excessively hot, not only does this cause changes in the direction of the height of the blade, but such a condition also causes the circumference of the blade to be extremely uneven. Normally, the leading edge, the trailing edge and the "dish" of a turbine blade will have relatively higher temperatures and the other components of the blade will have temperatures which are relatively lower. In order to prevent the materials in these high temperature areas from experiencing failure, one must add special emphasis to the cooling of these high temperature areas. In order to do this, people have made use of the method called jet-type cooling. This method, if one speaks in the most basic terms, is nothing more than raising the flow speed of the cooling air, thereby increasing the transferance of heat between the air and the blade and multiplying the drop in the temperature of the blade.

Figure 3 is a cross-section diagram of a turbine blade cooled by the jet-type method. In the heart of the turbine blade, there are installed guide vanes and on the surface of these guide

vanes there are small holes or cracks. These small holes or cracks are particularly good because they allow areas in the blade which particularly need cooling (such as the leading edge of the blade, the trailing edge of the blade and the interior wall surface of the "dish" of the blade) to be jet cooled by air and, because of this, to lower the temperature of the blade. This type of cooling method is often used at the same time as the convection method; however, the results from this type of cooling method are very obviously better than those achieved with the convection method.

Gas film cooling. In the dead of winter people often put on very, very thick cotton clothing in order to separate their bodies from the cold air outside and, because of this, to feel warm. In an engine it is also possible to make use of the "cotton clothing" type of method in order to prevent the temperature of blades from increasing. The gas film method of cooling is nothing more than this: one takes the cooling air from the base of the blade and conducts it into the interior cavity of the blade. It passes through the innumerable small holes in the wall of the blade and flows out. After this happens, there is formed on the surface of the blade a layer of gas film; this film functions just as though it were giving the turbine blade a set of "anti-heat clothing" to wear. This layer causes the surface of the blade and the hot air from the combustion to be separated and the temperature of the blade goes down. Figure 4 is a cross-sectional diagram of this type of cooling method. After use is made of this type of cooling method, it can cause the temperature of a blade to go down by 400° to 600°. However, this type of cooling method also has many shortcomings. These are due to the fact that the small holes in the surface of the blade are too numerous; this makes manufacture complicated and it obviously lowers the strength of the blade. Because of this, this type of cooling method is only used with crucial components that have extremely high temperatures.

Diffusion-type cooling. (This type of cooling is also called "sweat" cooling). Figure 5 is a cross-sectional diagram of a blade being cooled by the diffusion cooling method. The diffusion method of cooling represents a development of the concept of gas film cooling by one more step. With the gas film cooling method, it was only possible to form gas films in a certain number of high temperature areas of the blade and, in this way, protect the blade. With the diffusion type cooling method,

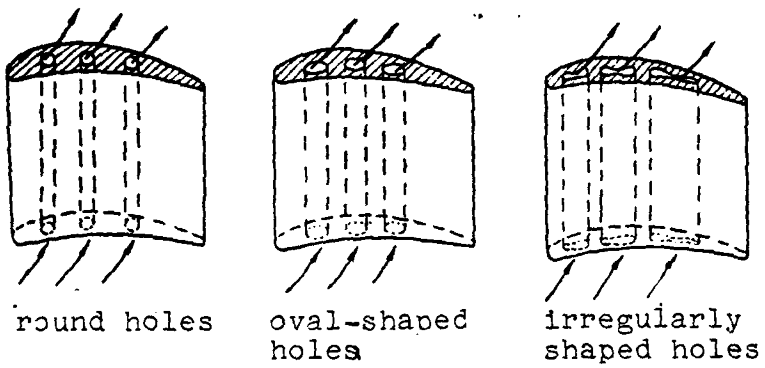

Figure 2. Different shapes of blade cooling holes.

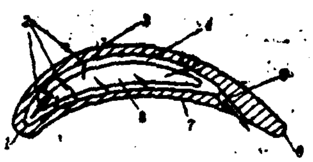

Figure 3. Cross-section of a blade with jet-type cooling.
1) leading edge; 2) jet cooling; 3) back of the blade; 4) Baffle; 5) convection cooling; 6) trailing edge; 7) blade disk; 8) radial flow inlet cavity

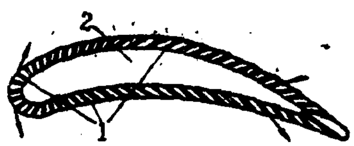

Figure 4. Cross-section diagram of a blade with gas film cooling.
1) cooling gas flow passages; 2) radial flow inlet cavity

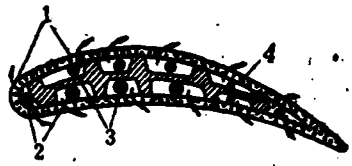

Fig. 5. Cross section of divergent cooled blade.

1) Divergent cooling; 2) metered air-feed holes; 3) radial flow inlet cavity; 5) honey comb network.

however, it is nearly possible to form a gas film over the entire blade. In this type of method, one makes use of honeycomb materials in the construction and the cooling air from the interior cavity passes through the wall surface and is finely distributed by the small holes it goes through. The cooling air which comes through the small holes, on the one hand, takes away the heat along the surface of the blade, but more importantly, it forms a very, very thin gas layer along the entire surface of the blade. Because of this, there is an obvious reduction in the amount of heat which is transferred from the high temperature combustion gases to the blade; as a result of this, the temperature of the blade drops and the reduction in temperature can reach as high as 500 to 800°. Because of this, people generally recognize the fact that the diffusion cooling method is the method of cooling which has the greatest developmental future. In all the world, everything has its advantages and disadvantages. The type of blade which we have just been talking about is not only difficult to manufacture, but the porous, honeycomb structure from which it is made is very easily oxidized. One must add to this the fact that these small holes can easily get plugged up with carbon particles from the combustion or with other pollutants. Because of this fact, there can be created localized buildups of excessive heat and this can cause the blade to burn up. At present, this type of cooling method is still in the research stage and is not ready to be used in actual engines.

At present, in aviation gas turbine engines, most use is made of convection, jet and gas film methods of cooling in combinations with each other. The intake temperatures of turbines already reach 1370° C. The experimental temperatures in the test aircraft of certain nations reaches 1520° C or more. It is reasonable to predict that there will be even further increases in the future.

After turbine blades have been cooled, one experiences not only an improvement in the capabilities of the engine but also an extension in the life of the engine. Because of this, it is possible to predict that along with the development of the gas turbine engine, the technology of turbine blade cooling will also improve with each passing day.